

# Developing innovative facades with improved seismic and sustainability performance

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## Abstract

Recent earthquakes have shown the vulnerability of conventional curtain wall glass claddings to seismic actions in large earthquakes. This paper undertakes an initial assessment of some innovative design concepts for glass claddings that can experience large earthquakes with minor or no damage, that enable building users to continue occupying a building without disruption.

A multi-criteria analysis based on a façade value framework – functional, strategic, financial and energy value – was used to undertake an initial assessment of four innovative low-damage glass cladding design concepts. The analysis indicates that the most promising design concept is fixed-sliding composite panels. These panels provide lateral stiffness to a building, enabling the required size of primary structural members to be reduced. During large earthquakes sliding connections ‘disconnect’ panels from the primary structure so they are not damaged due to the large lateral displacements of the structure.

Further research is required to develop and optimise the design of fixed-sliding panels and determine the relationship between panel design and building structural and energy performance and panel value.

Keywords: innovative low-damage seismic glass claddings

## 1. Introduction

Recent earthquakes, including the 2010-11 Canterbury earthquake sequence in New Zealand, have shown the vulnerability of facades and other non-structural building elements to seismic actions. The 6.2 Mw. earthquake that struck Christchurch, the largest city in the Canterbury region, on the 22<sup>nd</sup> February 2011 resulted in the loss of 185 lives and caused varying levels of damage to most buildings in the city, including the failure of curtain walls in some modern (<20 years old) commercial buildings<sup>1</sup>.

Well-designed modern buildings performed well during the earthquake in terms of life safety but many were extensively damaged and uneconomic to repair, resulting in large economic losses and disruption to building users and business. This prompted calls for building regulations in New Zealand to be tightened<sup>2</sup>, to require buildings are designed to protect lives and suffer only minor damage in major earthquakes (i.e. low-damage buildings), in order to protect assets better, reduce future economic losses and improve resilience.

Structural performance requirements in building regulations have not been tightened, however low-damage design has been applied to many buildings constructed in Christchurch since the earthquakes, in response to market demand. These buildings are typically designed to minimise damage to just structural elements, not the whole building. This limited approach to damage reduction is a questionable design philosophy, given potential economic losses from damage to non-structural elements typically exceed losses to structural elements<sup>3</sup> over a building's life. Clearly, there are barriers to the uptake of low-damage non-structural elements.

Barriers to the uptake of low-damage non-structural elements may include higher construction costs, lack of performance information and/or lack of design expertise<sup>4</sup>. Research at the University of Canterbury is addressing these barriers by investigating the design, behaviour and performance of low-damage buildings and building elements. The goal of this research is to reduce barriers to the development of low-damage buildings, in order to improve community resilience, sustainability and wellbeing.

This paper focuses on the development of low-damage glass claddings. The purpose of this paper is to develop an approach for assessing and developing new design concepts with the potential to significantly improve the

value of these building elements. An initial assessment of some novel design concepts for low-damage glass claddings in multi-storey commercial buildings is covered in the paper.

## **2. Improving the value of low-damage glass claddings**

### **2.1 Design strategies**

Low-damage glass claddings are designed to not attract damaging loads from their supports when there are seismically-induced displacements of the primary structure. Structural design strategies with the potential to achieve this include:

- Increase cladding displacement capacity<sup>5</sup>, i.e. increase the capability to accommodate displacements of the primary structure during major earthquakes, without attracting unwanted loads.
- Increase cladding strength<sup>5</sup>, i.e. increase the capacity to carry loads while remaining elastic.
- Increase cladding flexibility<sup>6</sup>, i.e. increase the capability to deform elastically.
- Reduce cladding displacement demand, i.e. reduce seismic displacements of the primary structure.
- Combination of above.

Design strategies typically focus on seismic movement gaps, connections to the primary structure and interstorey drifts. These strategies should be able to deliver improvements in the value of low-damage claddings. However, large improvements in value may require consideration of additional complementary strategies, such as:

- Utilise strength of cladding more efficiently, i.e. utilise cladding strength to reduce the size of primary structural elements.
- Improve multifunctional performance of the cladding, i.e. deliver multiple functions and/or performance benefits rather than just improved structural performance.
- Improve cladding appearance.
- Reduce cladding construction time.
- Combination of above.

Many potential design strategies for improving the value of low-damage claddings can be investigated when these two lists are combined.

### **2.2 Assessment framework**

The façade value framework presented by Heijer<sup>7</sup> is used here to assess novel concepts for low-damage glass cladding and to guide their development. This framework recognises four types of value:

- Functional value – how does the façade support the wellbeing, activities and productivity of the building's users, and improve their satisfaction and wellbeing?
- Strategic value – how does the façade support the identity, goals and competitive advantage of the organisation(s) using the building?
- Financial value – how does the façade affect the initial costs, life-cycle costs, market value and profitability of the organisation(s) using the building?
- Energy value – how does the façade affect the energy use and indoor environment of building users, and how does it affect the building's sustainability?

The relationship between the design and value of a façade is complex and not well understood. There is limited understanding, for example, of how value varies between developers, owners and different users, and how it changes with circumstances and time, such as before and after a major earthquake. These knowledge gaps limit the ability to use this value framework to quantitatively assess façades. Nevertheless, it is a useful tool for undertaking an initial assessment of innovative façade concepts.

### 3. Innovative low-damage glass claddings

#### 3.1 Design concepts

A low-damage cladding may need to accommodate ULS (Ultimate Limit State) interstorey drifts up to 2.5% without being damaged, for a multi-storey office building in New Zealand. This may equate to a lateral displacement of 90 mm or more, for a cladding panel that spans between floors. This is many times greater than the SLS (Serviceability Limit State) displacements that need to be accommodated without damage, in order to meet the requirements of building regulations.

Large ULS displacements may be accommodated by simply increasing the size of movement gaps around the edges of glazing but this 'simple' approach may require relatively wide, costly and obtrusive panel frame members. Some innovative design concepts for low-damage glass claddings that address these issues are shown in Table 1. It should be noted that the technical and economic feasibility of these concepts have not been fully assessed at this stage.

Low-damage design strategy	Low-damage cladding design concept			
	Sliding panel	Fixed-sliding panel	Fixed-sliding energy panel	Fast-erect fixed-sliding panel
Increase cladding displacement capacity	✓	✓	✓	✓
Increase cladding strength		✓	✓	✓
Reduce cladding displacement demand				
Increase cladding flexibility				
<b>Complementary strategy</b>				
Utilise cladding material strength		✓	✓	✓
Multifunctional performance			✓	
Improve cladding appearance		✓	✓	✓
Reduce cladding construction time			✓	✓

Table 1: Some innovative design concepts for improving the value of low-damage glass cladding systems

##### 3.1.1 Sliding panel

This concept, shown in Fig. 1, avoids damaging seismic loads being transferred from the primary structure to cladding panels through the use of sliding connections that 'disconnect' the cladding from the primary structure<sup>5</sup>. Sliding connections with the capability to accommodate large interstorey drifts have been successfully tested<sup>8</sup> but do not appear to be widely used in practice.

##### 3.1.2 Fixed-sliding panel

This concept fixes relatively stiff cladding panels to the primary structure in order to increase a building's lateral stiffness up to the SLS. Connections are designed to let panels slide when loads exceed the SLS, to limit stress in the cladding panel during large earthquakes. Fixed-sliding connections may allow a significant reduction of primary structural member sizes (>20%) due to the lateral stiffness provided by the cladding<sup>9</sup>. They may also make it easier to seal the cladding for weathertightness.

Using the composite action of cladding and primary structure to reduce the size of structural elements is not a new idea. It has been implemented in stressed building skin design<sup>10</sup> and is used in the structural design of automobiles and aeroplanes. It has proved difficult to implement for glass claddings<sup>5</sup> due to deformation incompatibilities between cladding and primary structure. Fixed-sliding connections that 'disconnect' and

destress cladding when loads exceed the SLS would help to address this issue

In order to maximise material efficiency, ideally the whole cladding panel – frame and glass – provides lateral stiffness. Research on the development of prefabricated double-skin composite panels<sup>11</sup>, with well-bonded glass-frame-glass layers, is progressing towards this goal. Composite construction may allow smaller cladding frame member sizes, with a more slimline look, as well as smaller primary structural member sizes.

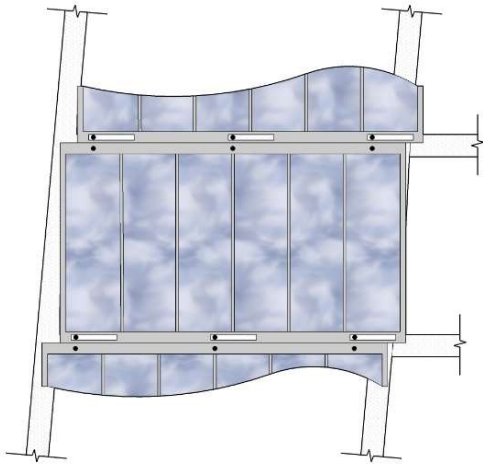


Figure 1: Sliding panel

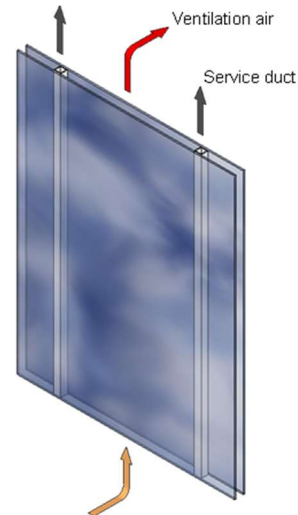


Figure 2: Double-skin energy panel

### 3.1.3 Fixed-sliding energy panel

This concept adds functionality to fixed-sliding double-skin composite panels by utilising cavities between the skins for service and/or ventilation ducts, as shown in Fig. 2.

Potential advantages from ventilating the cavities of double-skin panels include smaller HVAC equipment size, reduced building energy use and improved occupant comfort<sup>12</sup>. Reported advantages are variable<sup>13</sup> and depend on the design, function and operation of the cavities, the design of the building and the local climate. It appears that significant savings in cooling energy (>20%) may be possible for office buildings in temperate climates. Potential disadvantages, such as dust accumulation in the cavities, need to be considered when assessing this concept.

### 3.1.4 Fast-erect fixed-sliding panel

This concept is designed to reduce crane movements and construction time through lifting larger-than-normal prefabricated panels into position on a building under construction. Unit panels are inherently faster to construct than stick curtain wall systems. This concept extends this advantage by utilising relatively stiff fixed-sliding panels to enable larger panels to be lifted.

## 3.2 Assessment

A multi-criteria analysis (MCA) was undertaken to provide an initial assessment of the innovative low-damage glass cladding concepts, using Heijer's<sup>7</sup> façade value framework. The options were scored against each of the four values (i.e. functional, strategic, financial and energy) in this framework, using a 7 point ranking system, from +3 (significant advantage) to -3 (significant disadvantage) compared to a conventional stick curtain wall with sealed double-glazed cladding, for a mid-rise (4-6 storeys) office building located in Christchurch. An equal importance weighting was applied to the four values, recognising that weighting may vary significantly from one building project to the next. The MCA is summarised in Table 2 below.

### 3.2.1 Functional value

All of the low-damage cladding design concepts considered in this paper improve functional value by improving the usability of a building after a major earthquake. Or at least it provides peace of mind to building owners and users that this will be the case.

The slimline look of a fixed-sliding composite panel provides additional functional value by improving the well-being and satisfaction of building users.

It may be argued that the ventilated cavity of a fixed-sliding energy panel improves functional value by improving the thermal environment and productivity of building users working in a building's perimeter zone.

### 3.2.2 Strategic value

Buildings with superior sustainability command a rental premium in many real estate markets around the world. A building's superior sustainability can be promoted by drawing attention to its sustainability rating and its 'green' technologies that can be seen 'working'. Promoting the strategic value of resilient claddings is more difficult because they can't be seen 'working' (until they prove their worth in a major earthquake) and resilience rating tools are not well-developed.

Strategic value scores in Table 2 reflect these considerations.

### 3.2.3 Financial value

The initial costs of the low-damage panels will be higher than conventional stick curtain walls. However, fixed-sliding panels are expected to reduce the size of primary structural elements, which will help to offset their higher costs. Further research is required to evaluate the composite structural action of this type of panel and its cost-effectiveness.

The cost-effectiveness of fixed-sliding energy panels depend on the energy savings from ventilating their cavities, which depends on building design and location. The financial value score in Table 2 for this panel is based on a 20% saving in cooling energy, which is not expected to offset the higher costs of these panels.

Further research is required to determine the potential energy savings of these panels.

### 3.2.4 Energy value

The fixed-sliding energy panel received a positive score for this criterion in recognition of its superior energy performance.

Criterion	Low-damage cladding design concept				
	Stick curtain wall with sealed IGU <sup>1</sup>	Sliding panel	Fixed-sliding panel <sup>2</sup>	Fixed-sliding energy panel <sup>2</sup>	Fast-erect fixed-sliding panel <sup>2</sup>
Functional value	0	+	++	+++	++
Strategic value	0	+	+	++	+
Financial value <sup>3</sup>	0	-	+	0	++
Energy value	0	0	0	+	0

1. Double-glazed Insulating Glass Unit.

2. Composite panel construction

3. Based on an air-conditioned 4-6 storey office building in Christchurch with:

Building cost including fit out = \$5000/m<sup>2</sup>

Structure cost = 21% of building cost

External fabric cost = 13% of building cost

Cooling and ventilation energy use = 20 kWh/m<sup>2</sup> per annum

*Table 2: Summary of multi-criteria analysis.*

## 4. Discussion

The low-damage glass cladding design concepts considered in this paper all scored above conventional stick curtain walls, in the multi-criteria analysis undertaken to initially assess their potential value. The most promising concept – and the direction for future development of low-damage claddings – appears to be fixed-sliding composite panels that provide lateral stiffness to a building and reduce the required size of primary structural members. Additional value can potentially be created by utilising the stiffness of these panels to speed up their erection, and utilising their cavities to improve building energy performance.

Further research is required to develop and optimise the design of fixed-sliding panels and determine the relationship between panel design and building structural and energy performance. Research to determine the effect of panel design on required structural members sizes and cooling and ventilation equipment capacities and building energy use will enable their value to be assessed more accurately. This is the focus of ongoing research at the University of Canterbury.

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